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CONTRACT REPORT

DEPARTMENT OF SPECIAL PROGRAMS

Centre for Alternate Fuel Utilization

ADAPTATION OF ON-BOARD DIESEL EMISSIONS REDUCTION DEVICES FOR A JARVIS CLARK SCOOP TRAM

ONTARIO RESEARCH FOUNDATION

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Final Report No. 4089/G

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TABLE OF CONTENTS

		Page
1.	SUMMARY	1
2.	INTRODUCTION	1
3.	BACKGROUND	2
4.	SCOOP TRAM DESCRIPTION	3
5.	DESIGN AND DEVELOPMENT OF THE EMISSIONS CONTROL SYSTEM	4
6.	EMISSIONS AND PERFORMANCE TESTING	8
7.	RESULTS AND DISCUSSION	10
8.	CONCLUSIONS AND RECOMMENDATIONS	11

TABLE I - Temperature and Pressure Data Idle Mode

TABLE II - Temperature and Pressure Data High Idle Mode

TABLE III - Temperature and Pressure Data Load Stall Mode

TABLE IV - Gaseous Emissions Analysis Stock Exhaust System

TABLE V - Gaseous Emissions Summary Prototype 2 Exhaust System (Filters No EGR)

TABLE VI - Gaseous Emissions Summary Prototype 2 Exhaust System (Filters + EGR)

LIST OF FIGURES

FIGURE 1: A Jarvis Clark, JS-500 Scoop Tram

FIGURE 2: Jarvis Clark Stock Exhaust System Details

FIGURE 3: Intake Tube - Dimension Details

FIGURE 4: EGR and Intake Depression Valve Details

FIGURE 5: Prototype 1 Installation Showing a Downward Directing Exhaust

FIGURE 6: Prototype 1 Downward Facing Exhaust

FIGURE 7: Air Box Cover Details

FIGURE 8: Header Tube Dimension Details

FIGURE 9: Flange Dimension Details

FIGURE 10: Corning Filter Assembly - Dimension Details

FIGURE 11: Exhaust Tube - Dimension Details

FIGURE 12: Prototype 2 Upward Facing Exhaust Details

FIGURE 13: Prototype 2 Installation Showing the Upward Directing Exhaust

FIGURE 14: Magnehelic Gauge Panel

FIGURE 15: CO Emissions

FIGURE 16: THC Emissions

FIGURE 17: NO Emissions

FIGURE 18: NO_x Emissions

FIGURE 19: CO_2 Emissions

1. SUMMARY

A Corning filter/exhaust gas recirculation (EGR) emissions control system has been designed, fabricated and installed on a Jarvis Clark, JS500 scoop tram. Two exhaust outlet configurations were fabricated, one with a downward directing exhaust, the other with the exhaust pointing upward at a 25^{o} angle relative to grade. Emissions of CO, THC, CO , NO_x and NO were measured for three exhaust control strategies. The machine was also subjectively evaluated under simulated mucking conditions in a test area at ORF.

2. INTRODUCTION

This report is a summary of the activities carried out by ORF for the design, fabrication, installation and evaluation of an emissions control package on a Jarvis Clark 5-yard scoop tram. The control package incorporated exhaust gas recirculation in conjunction with ceramic diesel particulate filters. Several hardware configurations were investigated while considering variables such as durability, thermal loadings and flow dynamics. All designs were based on Deutz F8L 413 F/W engine performance and exhaust characteristics. The scoop tram was provided by Jarvis Clark Co. Ltd., (North Bay) as a gesture of their interest in the test program. Two, Corning ceramic diesel particulate filters were provided by CANMET.

The primary purpose of this program was to familiarize ORF staff with the exhaust system design, as well as installation on the vehicle. This familiarization would prepare staff for retrofitting of an emissions control package on a Wagner ST500 scoop tram at White Pine Mine in Michigan as part of a U.S. Bureau of Mines (USBM) program. The USBM program involves the development of a ceramic filter/EGR package on an engine dynamometer test bed and transferring and evaluating the technology in actual underground mining conditions. Emissions would be evaluated in the mine by Michigan Technological University (MTU) using their Mine Air Monitoring Lab (MAML).

3. BACKGROUND

Previous work by ORF and others has shown that high particulate control efficiencies on diesel exhaust emissions can be achieved with ceramic particulate filters. Ceramic filters were developed as a spin-off from technology used in ceramic support for automotive catalyst application. Corning filters are constructed in a honeycomb configuration with alternate channels blocked in a checkered fashion. The opposite end of the filter unit is similarly blocked, however, the checkerboard pattern is shifted by one channel. This configuration forces the exhaust gas to pass through the ceramic material and consequently provides for the filtering. Factors such as ceramic porosity, filter face area, filtration area, cell density and other variables can effect the filtering efficiency of these devices. Limited research work at an INCO mining operation have shown that the Corning filters will withstand some of the operating conditions experienced in underground mining conditions.

Exhaust gas recirculation has been widely used in the gasoline automotive market as a method of reducing oxides of nitrogen emissions. EGR combines a portion of the exhaust gas stream with the combustion air stream. The exhaust gases present in the air charge depletes the oxygen available for combustion and thereby reduces the peak flame temperature. Reduction of the flame temperature reduces the formation of nitrogen oxides.

EGR has only recently been considered for application to diesel engines. Some of the drawbacks of EGR for diesel engines are increased particulate emissions and increases in the brake specific fuel consumption. However, application of a combined ceramic filter in conjunction with EGR has been shown to effectively reduce nitrogen oxides and particulate emissions.

4. SCOOP TRAM DESCRIPTION

The underground mining vehicle tested in this report was a Jarvis Clark "Jarco Scoop" JS-500 scoop tram. The scoop tram was provided to the Ontario Research Foundation by Jarvis Clark Co. Ltd., of North Bay, Ontario. This vehicle is typical of the load-haul-dump type of machinery found in underground mine operations.

Figure 1 illustrates the JS-500 scoop tram and consists of the following basic components. To the extreme rear of the vehicle is the engine compartment, which is attached to the rear frame. The rear frame of the vehicle also contains the exhaust system, diesel fuel tank, hydraulic system, drive train, operator's compartment and the articulating steering mechanisms. The steel hinge pins of the articulating steering connect the rear frame of the vehicle to the forward frame. The forward frame of the JS-500 scoop tram carries a hydraulic boom which is connected to a 5 cubic yard capacity bucket. The operator's compartment features a side seating position which benefits the operator by providing improved visibility.

In terms of size, the JS-500 scoop tram is approximately 8.89 metres in length, 2.44 metres wide and 1.75 metres high. The scoop tram in operating form weighs 21,206 kg and is capable of lifting 6.8 metric tons of material. From a performance standpoint, the JS-500 has the ability to climb a gradient in excess of 25% and has a top speed on level ground of 28.8 km/hr.

One of the standard power plants of the JS-500 scoop tram is a Deutz Diesel F8L 714 F/W engine, (serial number 6286947) which has a mine service rating of 134 kW at 2300 RPM. This engine is an air cooled, V8 configuration, displacing 12.6 litres and develops 371 N.m torque at 1300 RPM. The Deutz Diesel engine is connected to a Clark industrial single stage torque converter with a stall ratio of 2.9:1. The transmission of the JS-500

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is a Clark full power shift unit with four forward and four reverse speeds. The articulating steering, dump and hoist capabilities of the JS-500 are hydraulically powered via two heavy duty, motor driven gear type pumps.

The standard equipment exhaust system of the JS-500 scoop tram has a USBM ventilation recommendation rating of 5664 standard cubic metres per minute. The exhaust system utilizes an Engelhard Industries PTX type 6D catalyst on each engine exhaust bank to reduce CO and HC emissions. The air cleaner system of the JS-500 scoop tram is a dry paper element type with a vortex pre-cleaner. The dry paper element is manufactured by Farr Industries (Jarvis Clark part #107755-A) and one air cleaner is provided for each of the two cylinder banks of the Deutz Diesel engine.

5. DESIGN AND DEVELOPMENT OF THE EMISSIONS CONTROL SYSTEM

During the design stage of the emission control package for the JS-500 scoop tram, we initially reviewed the vehicle's stock exhaust system. The stock JS-500 exhaust system (Figure 2) consists of three major components; the Englehard PTX catalyst, a 25.4 cm long section of convoluted steel tube and a chassis mounted muffler. A three hole flange joins the exhaust system to the engine exhaust manifold. A 7.6 cm I.D. carbon steel tube, bent into an 180° elbow, connects the Engelhard PTX catalyst to the Deutz flange. Following the PTX catalyst is a short section of 7.6 cm I.D. steel tubing, which joins approximately 25.4 cm of convoluted steel tube to the exhaust system. Lastly, a 90° steel elbow connects the system to the muffler via a seal clamp type fastener. The remainder of the particular joints are mated by shielded metal arc welding.

Reviewing our design goals, we investigated the possible negative effects that an EGR system may have upon engine operation. In previous EGR projects problem areas included:

a) horsepower losses associated with high intake air temperatures;

b) severe smoking produced through the lack of oxygen;

c) high hydrocarbon, CO emissions and particulate emissions due to the incomplete combustion.

Some time was spent on researching air to air heat exchangers as a method of reducing intake air temperatures. However, the expenses involved and the space constraints due to the sheet metal confines of the scoop tram made this idea unfeasible at this time.

Several prototype Corning filter/EGR configurations were drafted on paper. The initial designs favoured a bridged right and left exhaust tube with one central EGR valve feeding a bridged combustion air intake tube. These designs proved to be impractical due to their inherent complexity. In our final design it was decided to construct separate EGR - Corning filter emissions systems for each exhaust bank of the JS-500 scoop tram. In this form each bank would have its individual EGR valve feeding its own combustion air intake duct.

With regard to EGR valve design, several research organizations, such as Ricardo and Company Engineers in England, have experienced valve distortion and problems due to overheating with butterfly type EGR valves.[1] In Ricardo's case, distortion associated problems were so severe that alternative EGR valve designs were undertaken. It was felt that the EGR butterfly valve design could be utilized,providing that heat resistant materials were used during construction and that the location of the valve was as close as possible to the cooling air of the intake duct, as shown in Figure 3. Type 316 stainless steel was used in the manufacture of the butterfly plate and the support shaft (Figure 4). The remainder of the valve was constructed of carbon steel. The butterfly shaft end was silver-soldered onto a cam-type adjuster which locks into position via a lock bolt. One blind bushing and one open end bushing were silver-soldered onto the 7.2 cm I.D. steel tubing to provide sufficient support for the butterfly shaft to rotate. Special attention was paid in providing proper clearance between the butterfly shaft and the support bushings, to ensure that no siezing or gauling of materials would take place.

The intake depression valves are identical in construction to the EGR valves, however, the two dimensions indicated as (A) and (B), shown in Figure 4, are larger. These intake depression valves were constructed entirely of carbon steel since they do not experience high temperature conditions. During testing it was found that we could attain sufficient EGR percentages without having to use these depression inducing intake valves. Subsequently, these valves were locked into a wide open position for the remainder of our testing.

The first JS-500 scoop tram emissions system to be manufactured is designated as Prototype 1 shown in Figures 5 and 6. Initially, modifications to the air intake system were undertaken by re-directing the air boxes from their standard lateral direction to a rearward facing direction. The air box mounting plates were flame-cut to provide clearance for this modification, and new mounting holes for the air boxes were drilled. Air box shroud covers were manufactured by a local sheet metal shop and these were attached to the air boxes using the stock mounting clips, (Figure 7).

Figure 8 illustrates a header tube section for the Prototype 1 emission system which was made of carbon steel 7.62 cm I.D. tubing and short radius, 90° elbows. Deutz three hole flanges (part #336-6951) attached the header tube the engine manifold. A 25.4 cm long section of 7.6 cm I.D. stainless steel corrugated hose (Hydroflex #BNC 21-0) was provided to dampen vibrations from the rubber mounted Deutz engine to the chassis mounted exhaust. Finally, a four hole carbon steel flange, as shown in Figure 9, was welded to the corrugated hose section. This header tube section of Prototype 1 was oxy-acetylene welded using an AWS class A5.2 filler rod.

The Corning filters from the JS-500 scoop tram emission package were provided by CANMET in Ottawa. Exhaust flanges were fabricated and arc welded to the Corning filters using a UTP type 316 electrode. Deutz Diesel air cleaner mounting brackets, shown in Figure 10, were used to attach the Corning filters onto the vehicle lateral support mounts. These lateral support

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mounts were arc welded onto the JS-500 scoop tram chassis using Soudotec #222 electrodes.

The Corning filter was directly attached by a flange connection to the exhaust tube section shown in Figure 11. Figure 6 illustrates the exhaust tube section featuring a downward directing exhaust system, similar to the stock scoop tram exhaust. Prior to the short radius 90° elbow of the exhaust tube, an upward directed EGR inlet tube was located to transfer exhaust gases to the intake tube. The connection between the exhaust tube and inlet tube was accomplished through the use of carbon steel 22° lipped flanges. These lipped flanges when used in conjunction with stainless steel 22° V-band clamps provided a very good seal.

The inlet tube contains the EGR valve and the depression inducing intake valve. The EGR valve is located less than 3 inches from the main 4 inch intake tube to insure that the EGR valve is sufficiently cooled by ambient intake air. As with the exhaust tube section, 22° lipped flanges with V-band clamps are used to connect the air box and the exhaust section of the Prototype 1 emission control package.

The Prototype 1 emission control package for the JS-500 scoop tram was succeeded by Prototype 2 package, as shown in Figures 12 and 13. This succession took place due to two specific problem areas which we felt could be alleviated. The first problem was the fact that the inlet tube of the EGR deviated from the confines of the scoop tram sheet metal. In order to correct this problem, we lowered the inlet tube approximately 2½ inches and reduced the total length by 6 inches. This change effectively protected the inlet tube from any potential damage which could occur in the mine environment. The second change implemented was the addition of an upward directed exhaust outlet pointed at a 25° angle relative to grade. This upward direction change was initiated after consultations with John Johnson of the Michigan Technological University (MTU). In his SAE paper No. 810684 Johnson stated "rearward directed exhaust was shown to enhance the natural ventilation in that the cool mine air flowed into the bottom of the drift and the diluted exhaust gases flowed out of the top". The modified system was shown by Johnson

to reduce pollutant concentrations by 50%, over the standard system which was directed out of the side of the vehicle at the floor level.

Following the two modifications described, we became concerned over the possibility that some degree of "short circuiting" might occur between the exhaust outlet and the intake air tract. However, during emissions testing no problems arose and it was accepted that the gas exit velocity from the exhaust duct was sufficiently powerful to prevent this from occurring.

The only other modification performed to the JS-500 scoop tram was the addition of the control panel as shown in Figure 14. Five Magnehelic gauges were installed to monitor exhaust temperatures, intake vacuums and effective EGR pressures after the Corning filters. The exhaust backpressure gauges were utilized to determine the degree of Corning filter loading,as well as to monitor possible auto-regeneration occurrences. The intake vacuum gauges indicated the condition of the dry element air cleaners, in relation to the degree of particulate emission loading.

6. EMISSIONS AND PERFORMANCE TESTING

The Jarvis Clark scoop tram was subjectively evaluated for operation and performance in a test area at ORF prior to exhaust control equipment modifications. One of the two filter units provided by CANMET had been previously used, and a significant amount of diesel particulate material was noticed on the filter face. After both filters were installed (used filter on the left bank) the vehicle was subjected to simulated mucking operations. It was observed that the left filter backpressure was excessively high (>100 cm H_2O) after a very short period of operation. Attempts to regenerate the filter on the vehicle by operating the engine at high loads were unsuccessful. The filter was then reversed such that the exhaust flow was allowed to back purge the filter. Clouds of black particulate matter were released after the engine was started and allowed to operate at high idle conditions. The

filter was then re-installed in its original configuration to observe the exhaust backpressure. It was found that the backpressure was still excessive so the filter was removed from the vehicle and placed in an autoclave. After allowing the filter to heat at 500°C for 5 hours the filter was again installed on the vehicle.

Following the above events, the left bank backpressure was reduced to levels observed for the right bank (≈25 cm H_20). During subsequent field trials the left bank backpressure increased at a much faster rate than that observed for the right bank. This characteristic may have resulted from a layer of residual non-combustible ash material that remained on the filter surface. The left filter required one further heating in an autoclave to regenerate the filter.

Three exhaust configurations were used to evaluate the characteristics of each in terms of temperature and pressure profile as well as emissions reduction potential. The three exhaust configurations were as follows:

- Standard exhaust with Engelhard catalysts.
- Modified exhaust with Corning filters. (Prototype 2)
- Modified exhaust with Corning filters and EGR. (Prototype 2)

Three engine operating modes of idle, high idle and load stall were used to evaluate the systems. These modes produced low flow/low temperature, high flow/low temperature and high flow/high temperature exhaust conditions, respectively. The conditions represent operating extremes experienced in a typical LHD cycle. Load stall tests were performed for a maximum of 25 seconds to prevent overheating of the torque convertor and transmission.

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7. RESULTS AND DISCUSSION

Exhaust system temperature and pressure data are presented in Tables 1, 2 and 3 for the idle, high idle and load stall modes, respectively. Idle mode exhaust gas temperatures before the control device (catalyst, filter) were lower than 120°C for all exhaust configurations tested. The considerable variation in intake air temperature was due to the heat discharge from the air cooled engine. Wind speed and direction also contributed to localized hot and cold zones in the area of the combustion air intake. The left bank backpressure is higher than the right bank for Prototype 2 exhaust configuration with and without EGR.

Table II shows that pre-control device exhaust gas temperatures increase to approximately 350°C. Temperatures generally decrease across the control device. Exhaust backpressure increases with increasing engine speed due to the greater exhaust gas flow. The backpressures are lower than the 10 kPa maximum specified by Deutz. Backpressures for the left bank show similar trends to that observed for the idle mode.

The exhaust gas temperature profile across the control device increased (Δt 30°C) on the right bank only when EGR was applied, (Table III). Engine speed measurements were not taken for the load stall tests due to the short test duration.

Gaseous emissions test results are given in Tables IV, V, VI for the standard, filter and filter/EGR exhaust configurations, respectively. Table IV and Figures 15 and 16 show that CO and THC concentrations are effectively reduced during high idle and load stall conditions. The catalysts appear to reduce the NO_2 concentration (see Figure 15) at low and intermediate exhaust temperatures (idle and high idle).

Data provided in Table V and Figure 18 shows that No_x concentrations are generally lower with the Corning filter installation compared to the standard exhaust system. Concentrations of THC were also generally lower with the Corning filter exhaust system.

Table VI shows that concentrations of oxides of nitrogen are reduced considerably (up to 52%) when EGR is used in conjunction with the Corning filters, relative to uncontrolled exhausts. Mass emissions of NO_x, therefore, would be reduced by up to 60% due to the 8% reduction in exhaust flow as a result of EGR. It should be noted that the exhaust flow reductions due to EGR are 13% for idle mode, 12% for high idle mode and 8% for load stall. These flow reductions must be taken into consideration when reviewing the emissions concentration data given in this report.

CO concentrations are lower in idle mode when EGR is employed and are higher in the other two modes. The scatter in hydrocarbon concentration data does not allow for any conclusion to be drawn with EGR effects on THC.

Figures 15 through 19 graphically illustrate the emissions comparisons for the three exhaust systems tested.

8. CONCLUSIONS AND RECOMMENDATIONS

A combined Corning filter/EGR emission control package for a Deutz F8L 413 F/W has been successfully tested on a Jarvis Clark JS-500 scoop tram. Several points observed during this study require highlighting as follows.

- Given the program cost constraints the selected hardware package consisted of one filter/EGR unit per bank of the engine.
- Reductions in NO_x concentrations of up to 52% were observed when EGR was employed.
- Engine power output and BSFC could not be determined due to the limited scope of this study.

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- Further work is required to expand on the optimization of a combined filter/EGR emission control package.

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TABLE I

Temperature and Pressure Data Idle Mode

Exhaust System Configuration	Engine Speed RPM	Temperatures °C				Pressures kPa	
		Before Control Device	After Control Device	Intake Air	Ambient Air	Before Control Device	Intake Air
1. Stock							
Left Bank	755	116	103	36	8	0.95	0.25
Right Bank	755	108	97	28	22	1.20	0.25
2. Prototype 2 No EGR							
Left Bank	700	94	89	37	14	1.49	0.25
Right Bank	700	86	95	29	14	0.25	0.25
3. Prototype 2 with EGR							
Left Bank	700	92	94	34	12	1.74	0.25
Right Bank	700	109	99	47	12	1.04	0.25

Note: -Maximum backpressure limit 10 kPa

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TABLE II

Temperature and Pressure Data High Idle Mode

Exhaust System Configuration	Engine Speed RPM	Temperatures °C				Pressures kPa	
		Before Control Device	After Control Device	Intake Air	Ambient Air	Before Control Device	Intake Air
1. Stock							
Left Bank	2465	353	350	51	9	4.98	1.41
Right Bank	2465	338	352	64	22	5.98	1.24
2. Prototype 2 No EGR							
Left Bank	2440	271	268	41	17	7.47	1.49
Right Bank	2440	260	251	35	15	3.49	1.43
3. Prototype 2 with EGR							
Left Bank	2440	276	277	57	11	8.47	1.49
Right Bank	2440	342	264	62	5	4.48	1.49

Note: - Maximum backpressure limit 10 kPa

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TABLE III

Temperature and Pressure Data Load Stall Mode

Engine System Configuration	Engine Speed RPM	Temperatures °C				Pressures kPa	
		Before Control Device	After Control Device	Intake Air	Ambient Air	Before Control Device	Intake Air
1. Stock							
Left Bank	N.D.	550	≈500	50	21	5.98	1.37
Right Bank	N.D.	568	≈500	57	7	6.97	1.24
2. Prototype 2 No. EGR							
Left Bank	N.D.	432	409	42	N.D.	4.98	1.56
Right Bank	N.D.	430	426	44	N.D.	2.49	1.49
3. Prototype 3 with EGR							
Left Bank	N.D.	444	433	55	5	6.97	1.49
Right Bank	N.D.	517	550	56	4	7.47	1.49

N.D. - Data not available

Note: - Maximum backpressure limit 10 kPa

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TABLE IV

Gaseous Emissions Analysis

Stock Exhaust System

Gaseous Constituent	Location	Left Bank			Right Bank		
		Idle	High Idle	Load Stall	Idle	High Idle	Load Stall
CO_2 %	Before Catalyst	2.2	4.2	8.2	2.4	3.8	8.0
	After Catalyst	2.0	4.0	8.4	2.0	3.8	8.2
CO ppm	Before Catalyst	90	105	210	100	115	275
	After Catalyst	65	35	85	75	40	35
THC ppm	Before Catalyst	15	80	75	20	90	90
	After Catalyst	15	30	33	19	36	45
NO_x ppm	Before Catalyst	240	420	690	200	360	530
	After Catalyst	240	410	640	190	320	595
NO ppm	Before Catalyst	200	365	610	160	330	520
	After Catalyst	210	365	560	180	310	530
NO_2 ppm	Before Catalyst	40	55	80	40	30	10
	After Catalyst	30	45	80	10	10	65

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TABLE V

Gaseous Emissions Summary

Prototype 2 Exhaust System (Filters No EGR)

Gaseous Constituent	Location	Left Bank			Right Bank		
		Idle	High Idle	Load Stall	Idle	High Idle	Load Stall
CO_2 %	Before Filter	2.0	4.1	8.0	2.3	4.0	8.4
	After Filter	2.0	4.0	8.0	2.0	4.0	8.0
CO ppm	Before Filter	60	110	150	75	135	160
	After Filter	75	120	220	65	125	185
THC ppm	Before Filter	22	75	69	16	90	87
	After Filter	17	56	68	19	72	100
NO_x ppm	Before Filter	180	315	530	180	280	500
	After Filter	170	310	500	175	290	500
NO ppm	Before Filter	145	270	490	140	230	470
	After Filter	145	280	480	130	270	470
NO_2 ppm	Before Filter	35	45	40	40	50	30
	After Filter	25	30	20	45	20	30

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TABLE VI

Gaseous Emissions Summary

Prototype 2 Exhaust System (Filters + EGR)

Gaseous Constituent	Location	Left Bank			Right Bank		
		Idle	High Idle	Load Stall	Idle	High Idle	Load Stall
CO_2 %	Before Filter	2.4	5.0	9.2	2.2	4.6	9.0
	After Filter	2.4	5.0	9.0	2.2	4.6	9.0
CO ppm	Before Filter	45	125	225	65	160	275
	After Filter	45	135	240	65	125	275
THC ppm	Before Filter	21	77	102	21	83	120
	After Filter	15	78	99	18	96	135
NO_x ppm	Before Filter	180	300	330	175	275	350
	After Filter	180	290	350	190	285	350
NO ppm	Before Filter	140	240	315	140	240	305
	After Filter	150	230	320	150	280	340
NO_2 ppm	Before Filter	40	60	15	35	35	45
	After Filter	30	60	30	40	5	10

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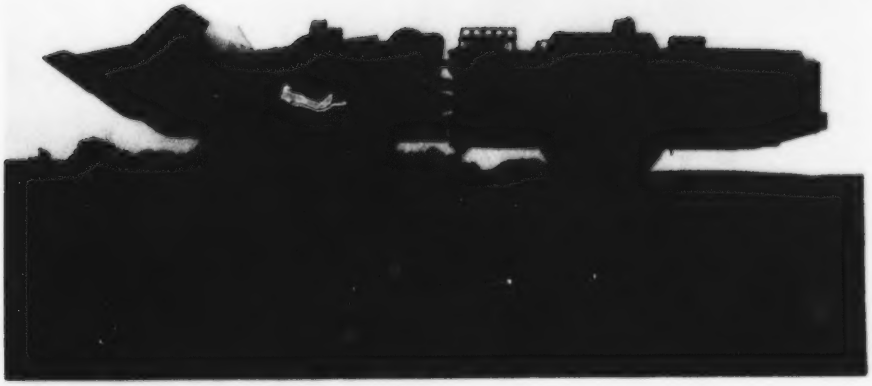


Figure 1: A Jarvis Clark, JS-500 Scoop Tram

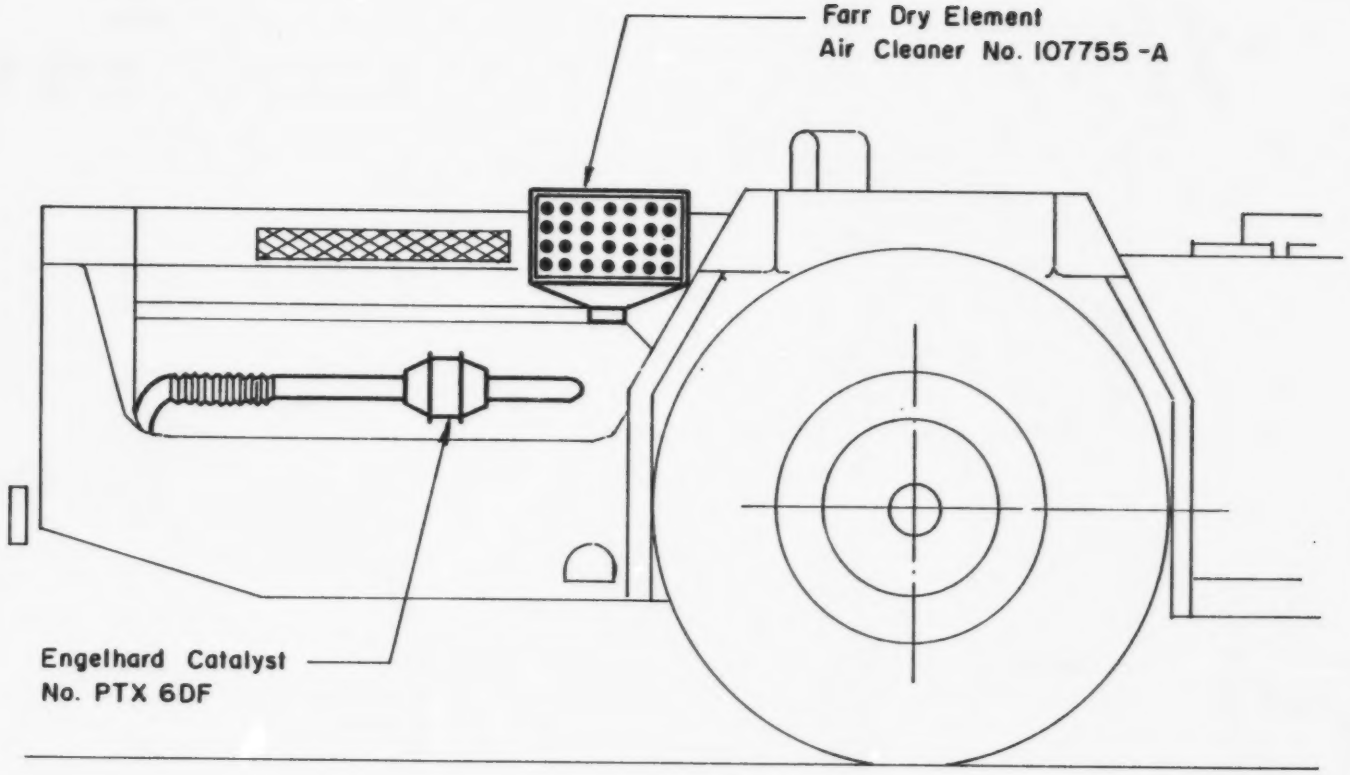


FIGURE 2: JARVIS CLARK STOCK EXHAUST SYSTEM DETAILS

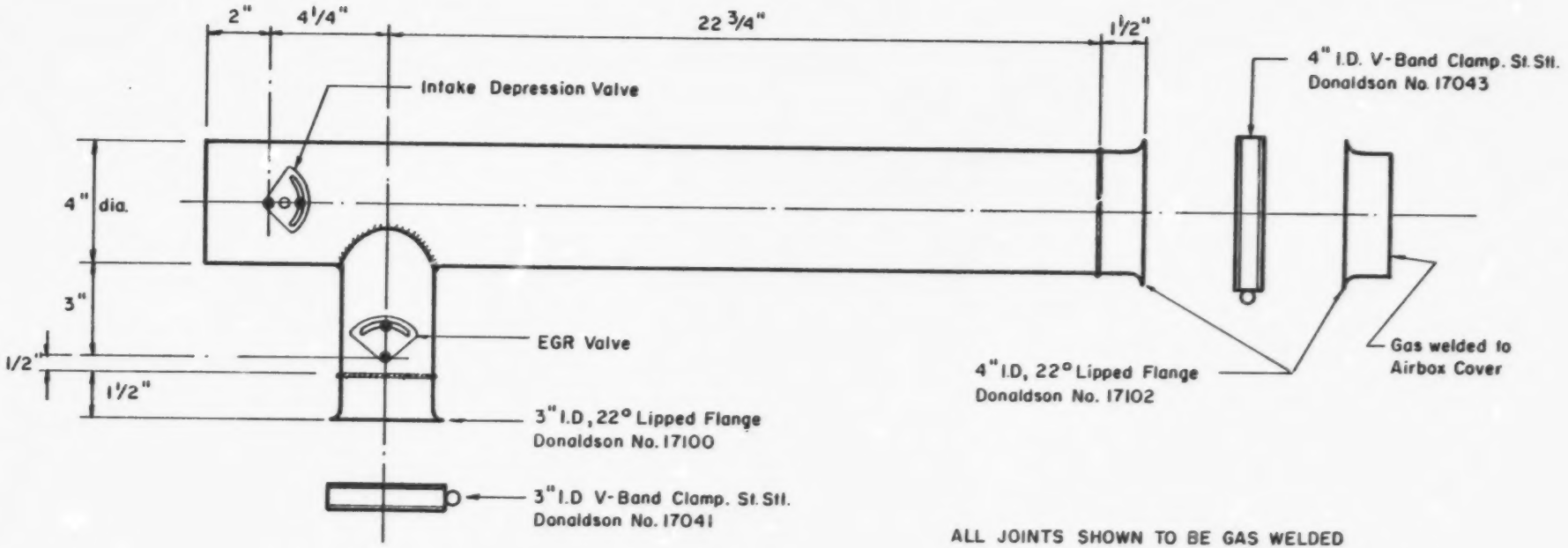


FIGURE 3: INTAKE TUBE - DIMENSION DETAILS.

MATERIALS : BUTTERFLY VALVE & STEM OF
EGR VALVE : 316 S.S
REMAINDER OF VALVE : CARBON STL.
INTAKE DEPRESSION VALVE : ALL CARBON STL.

NOTE : FOR EGR VALVE DIMENSIONS (A) & (B) WOULD BE 3 1/2" & 2 3/4" RESPECTIVELY

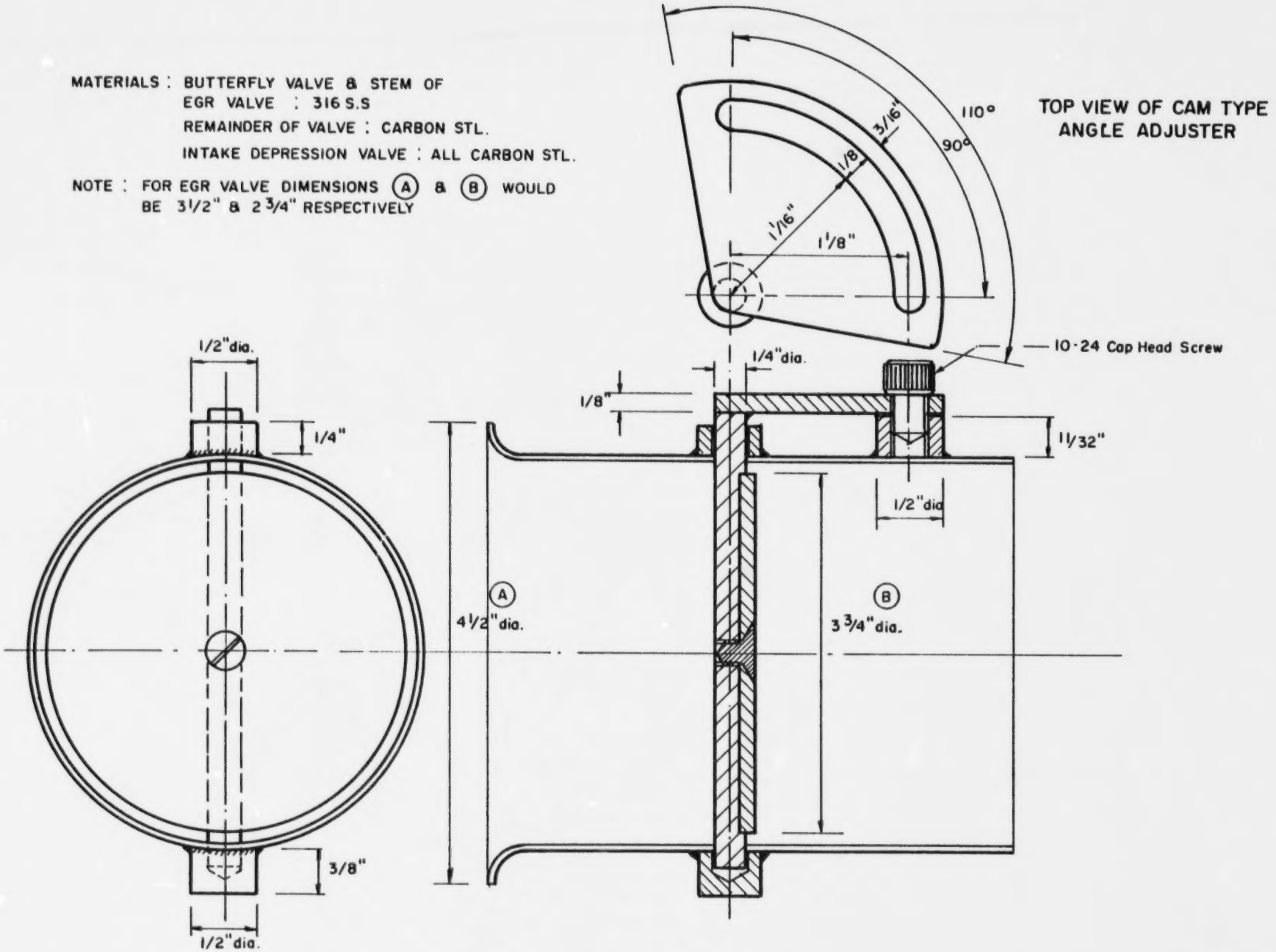


FIGURE 4: EGR & INTAKE DEPRESSION VALVE DETAILS

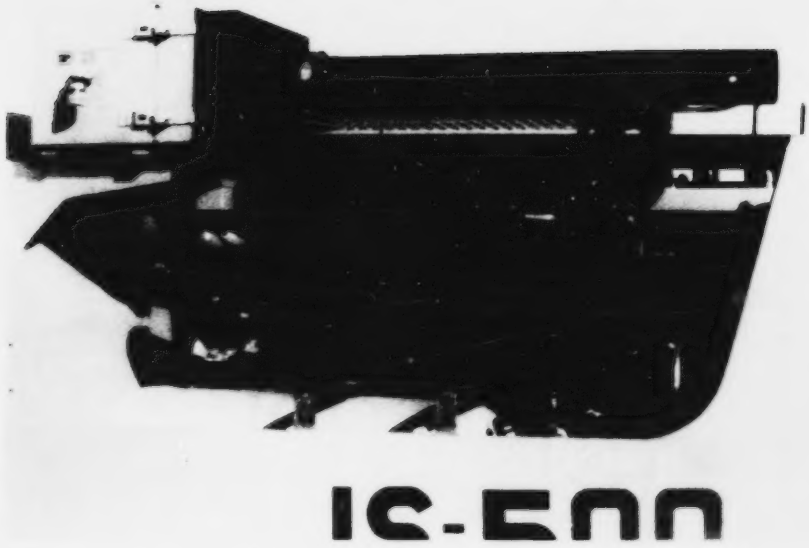
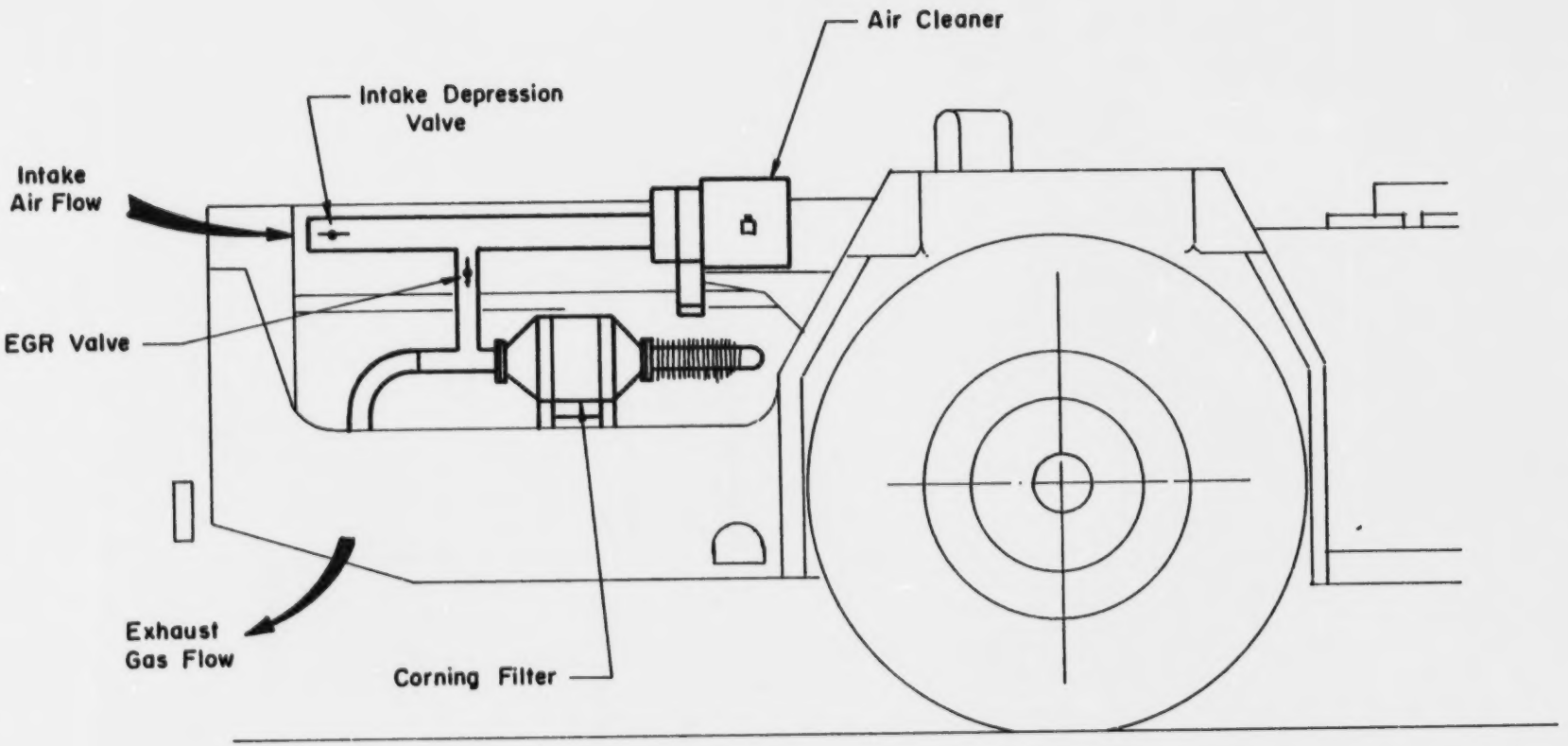
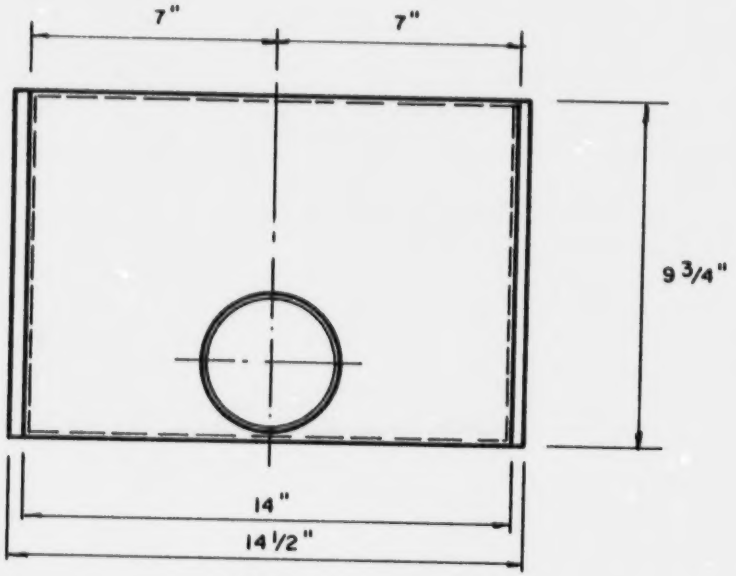


Figure 5: Prototype 1 Installation Showing a Downward Directing Exhaust



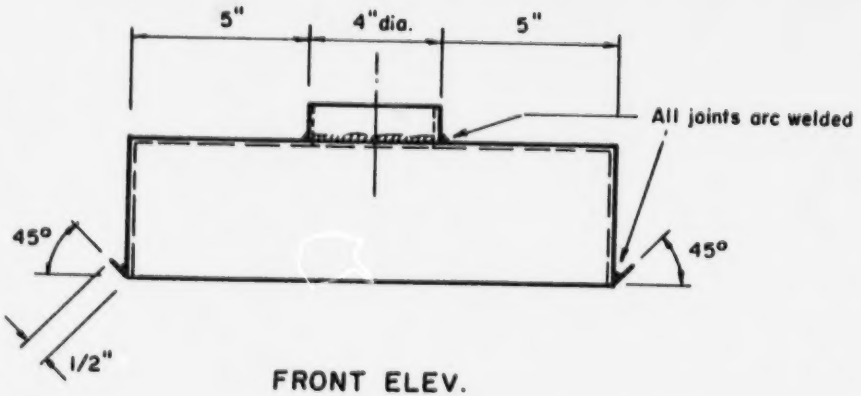
Note : One side only of machine shown, other side typical.

FIGURE 6: PROTOTYPE No. I DOWNWARD FACING EXHAUST.

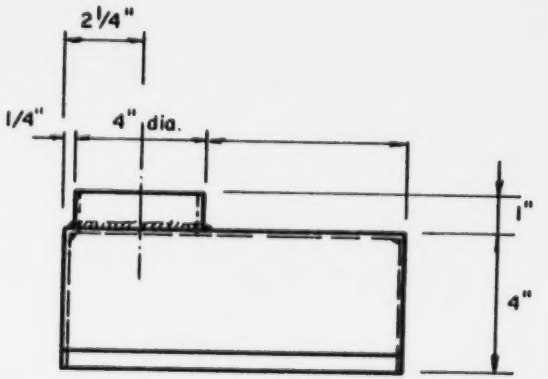


PLAN

Material. : 1/8"Thk. Mild Stl. Sheet.

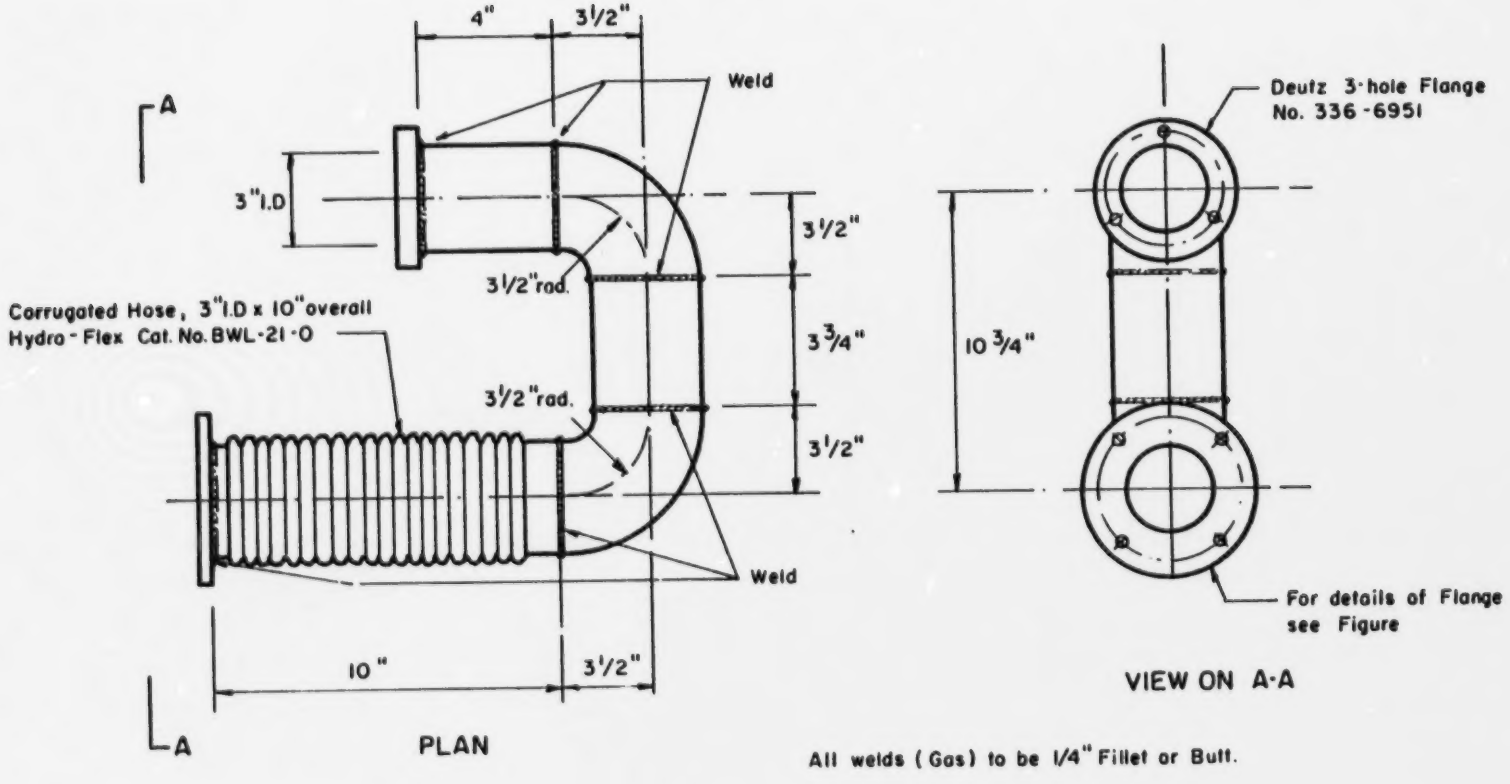


FRONT ELEV.



SIDE ELEV.

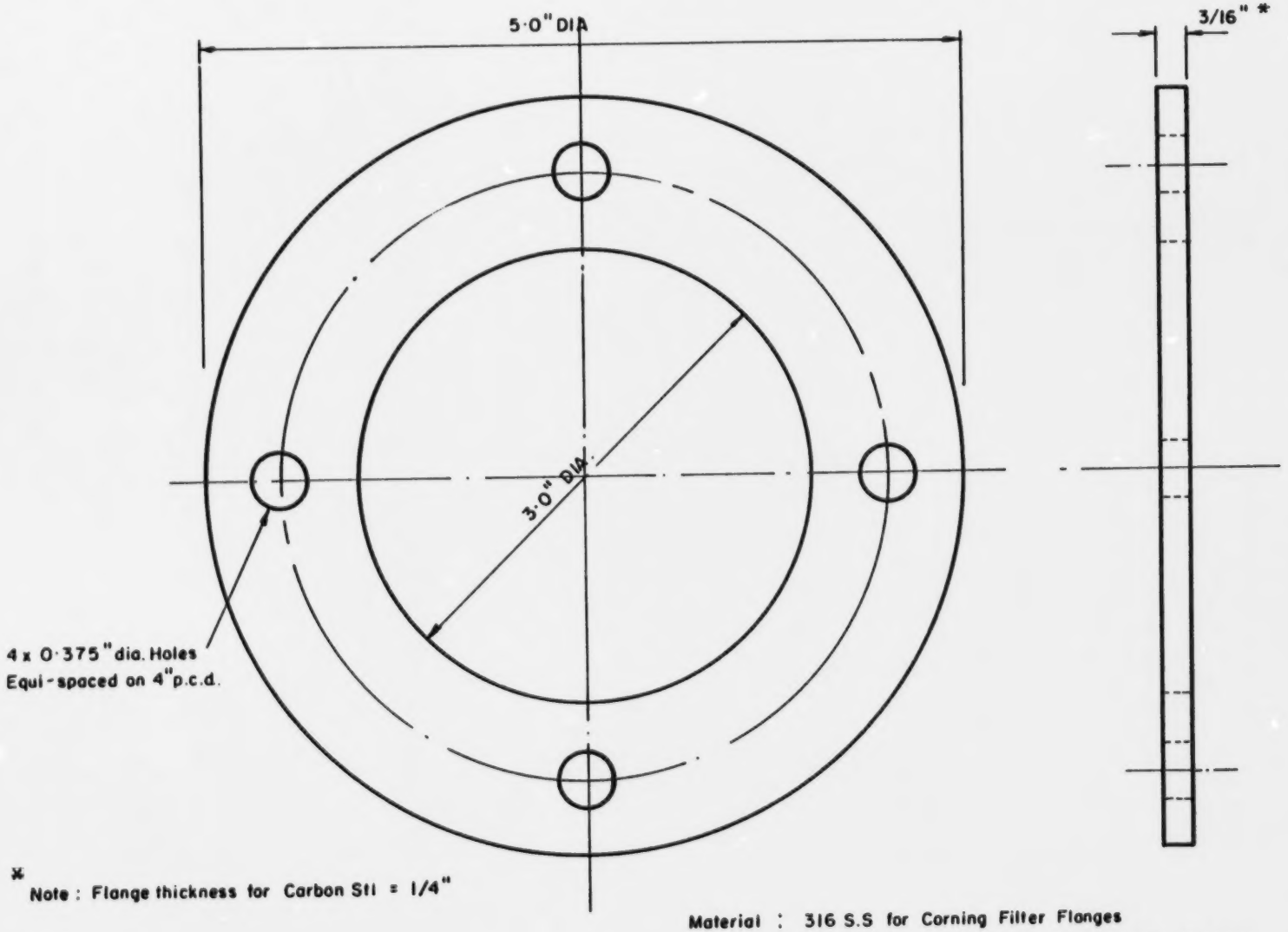
FIGURE 7: AIR BOX COVER DETAILS



All welds (Gas) to be 1/4" Fillet or Butt.

Material : 16g Carbon Stl. Tube (3"I.D)
Corrugated Hose : 304 S.S.

FIGURE 8: HEADER TUBE DIMENSION DETAILS



* Note : Flange thickness for Carbon Stl = 1/4"

Material : 316 S.S for Corning Filter Flanges
Carbon Stl for Header and Exhaust Tube Flanges

FIGURE 9: FLANGE DIMENSION DETAILS

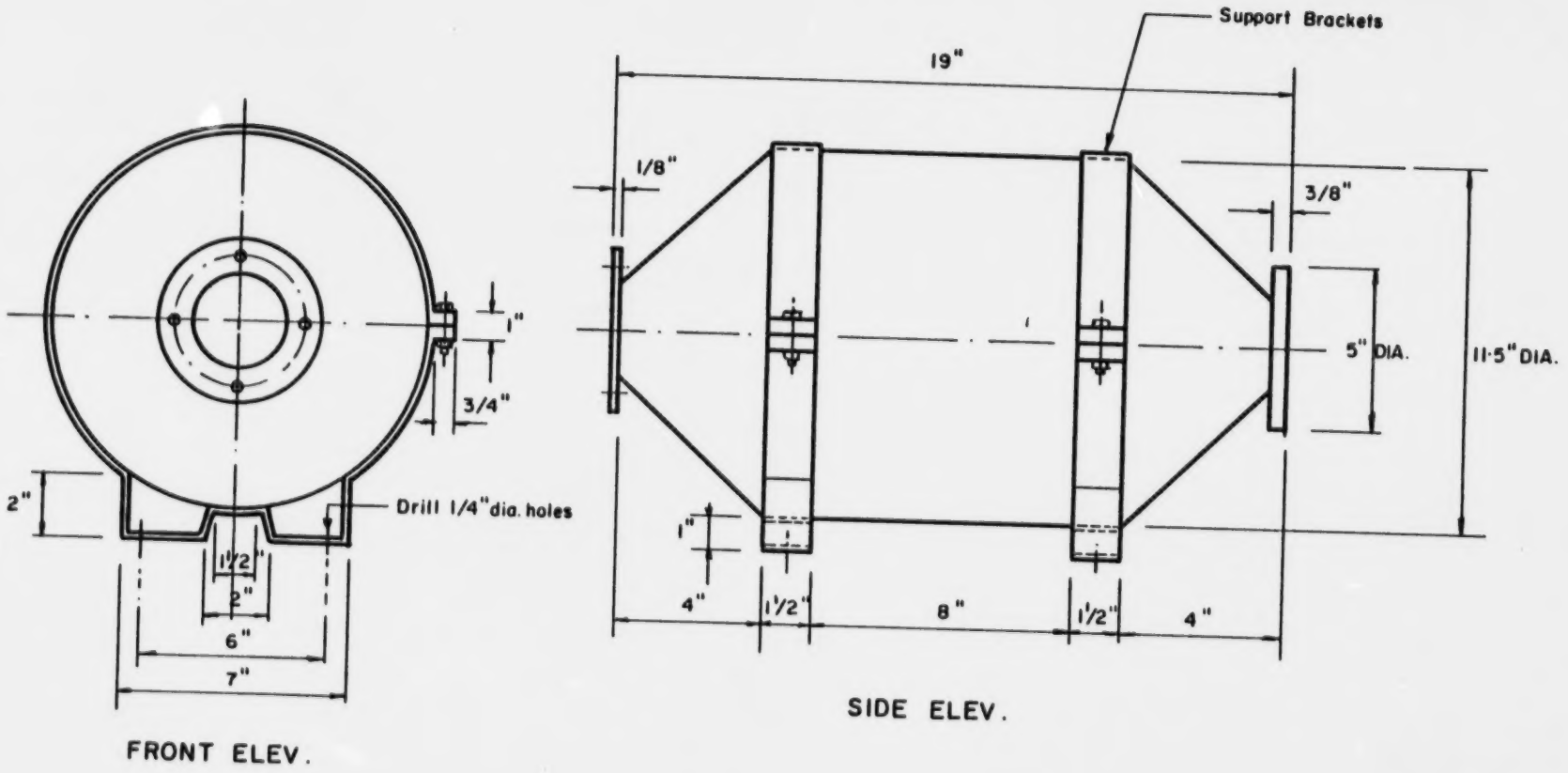


FIGURE 10: CORNING FILTER ASSEMBLY - DIMENSION DETAILS

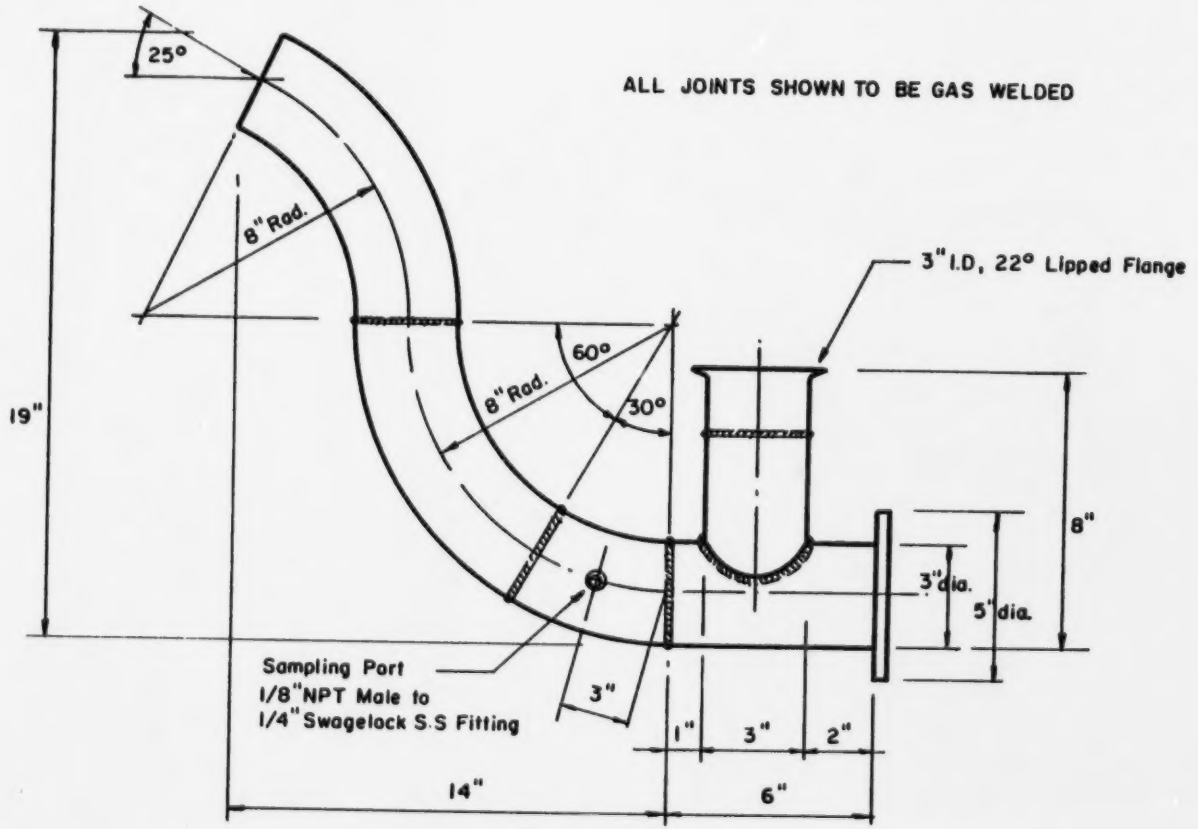


FIGURE 11: EXHAUST TUBE - DIMENSION DETAILS

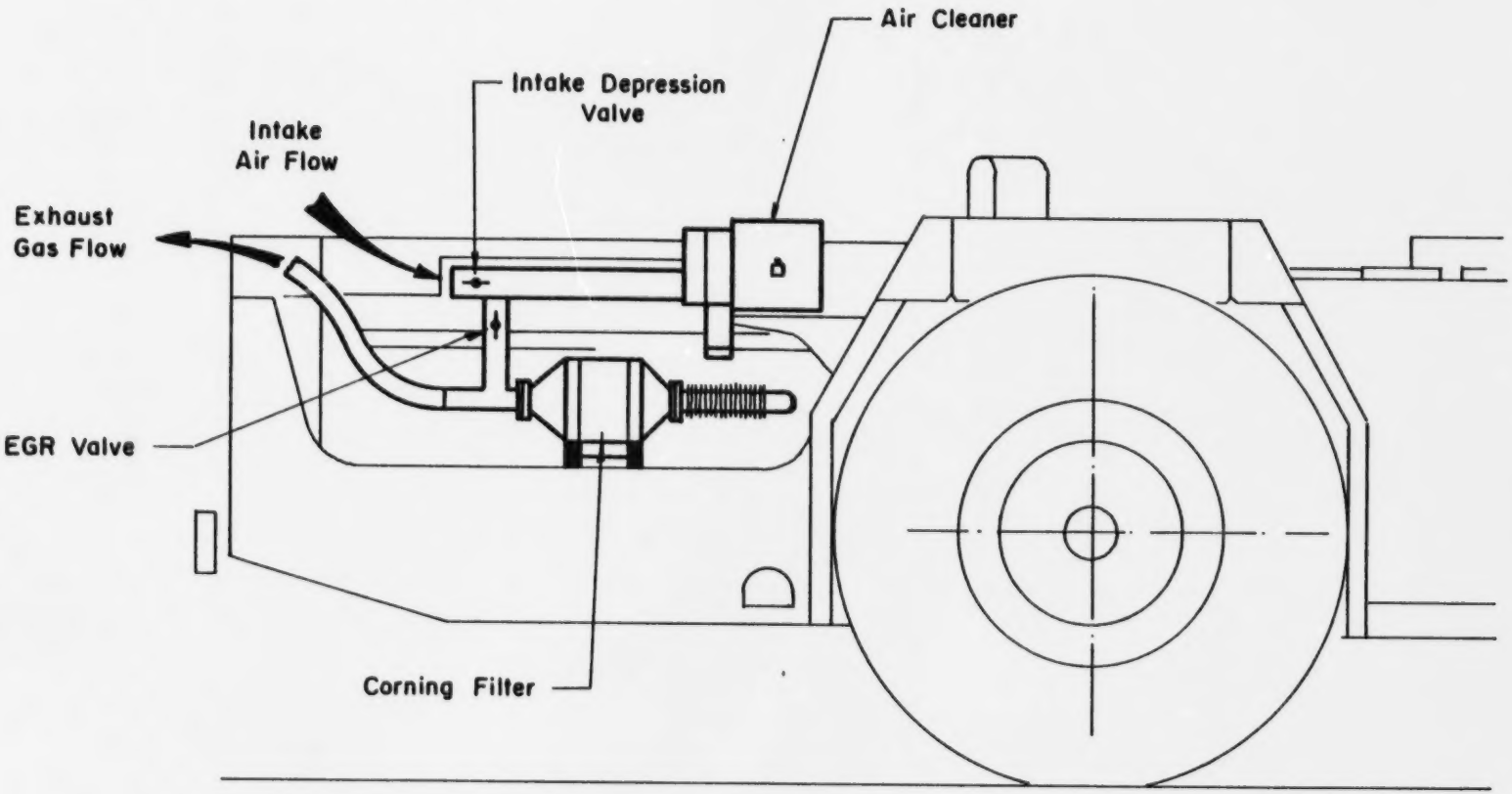


FIGURE 12: PROTOTYPE No.2. UPWARD FACING EXHAUST DETAILS

Figure 13: Prototype 2 Installation Showing the Upward Directing Exhaust

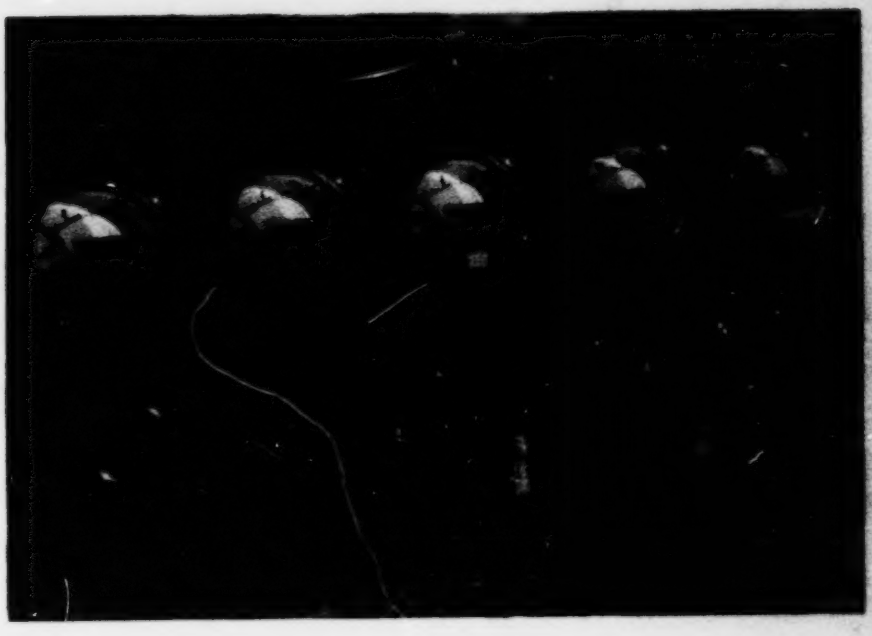


Figure 14: Magnehelic Gauge Panel

Figure 15: CO Emissions

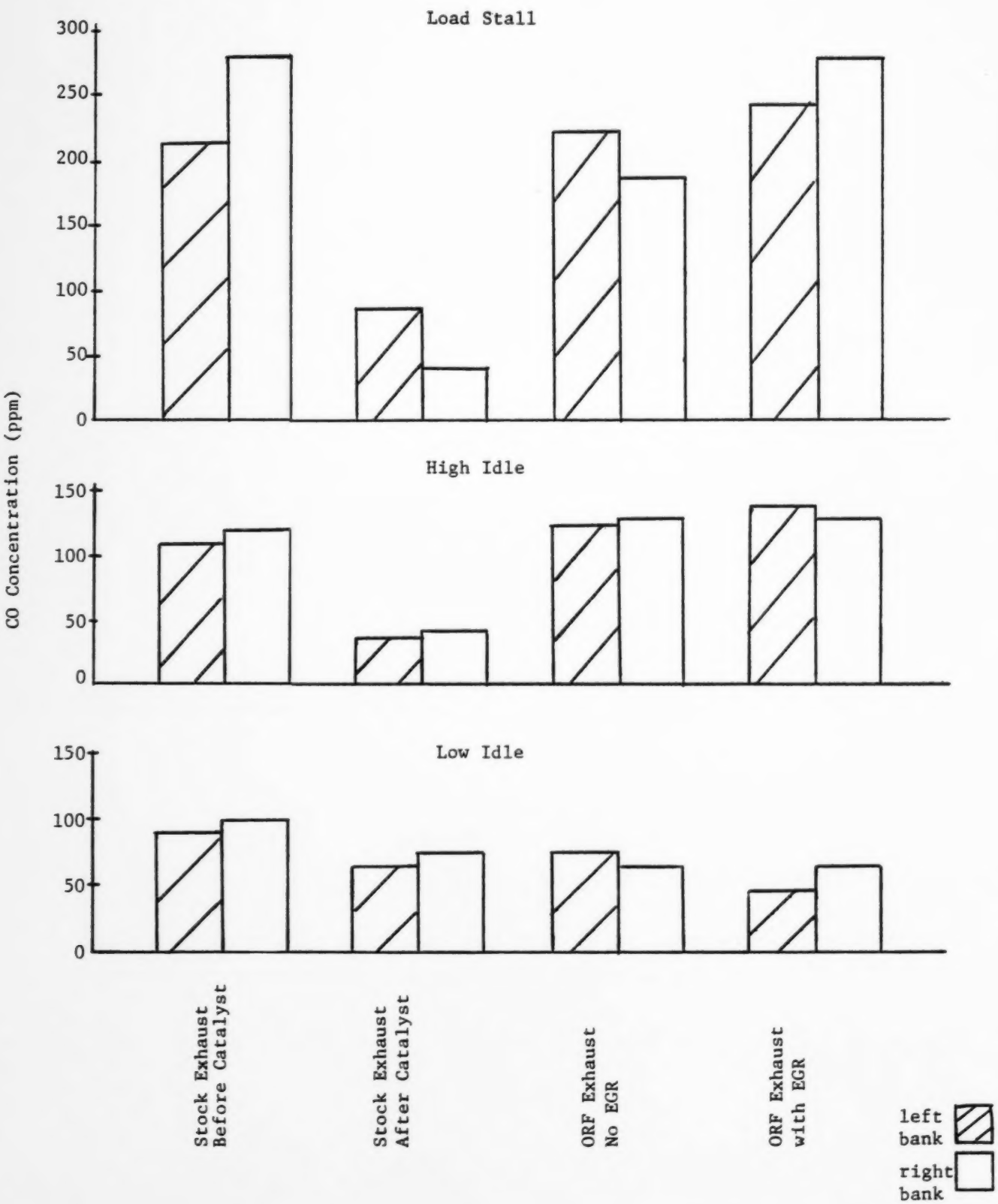


Figure 16: THC Emissions

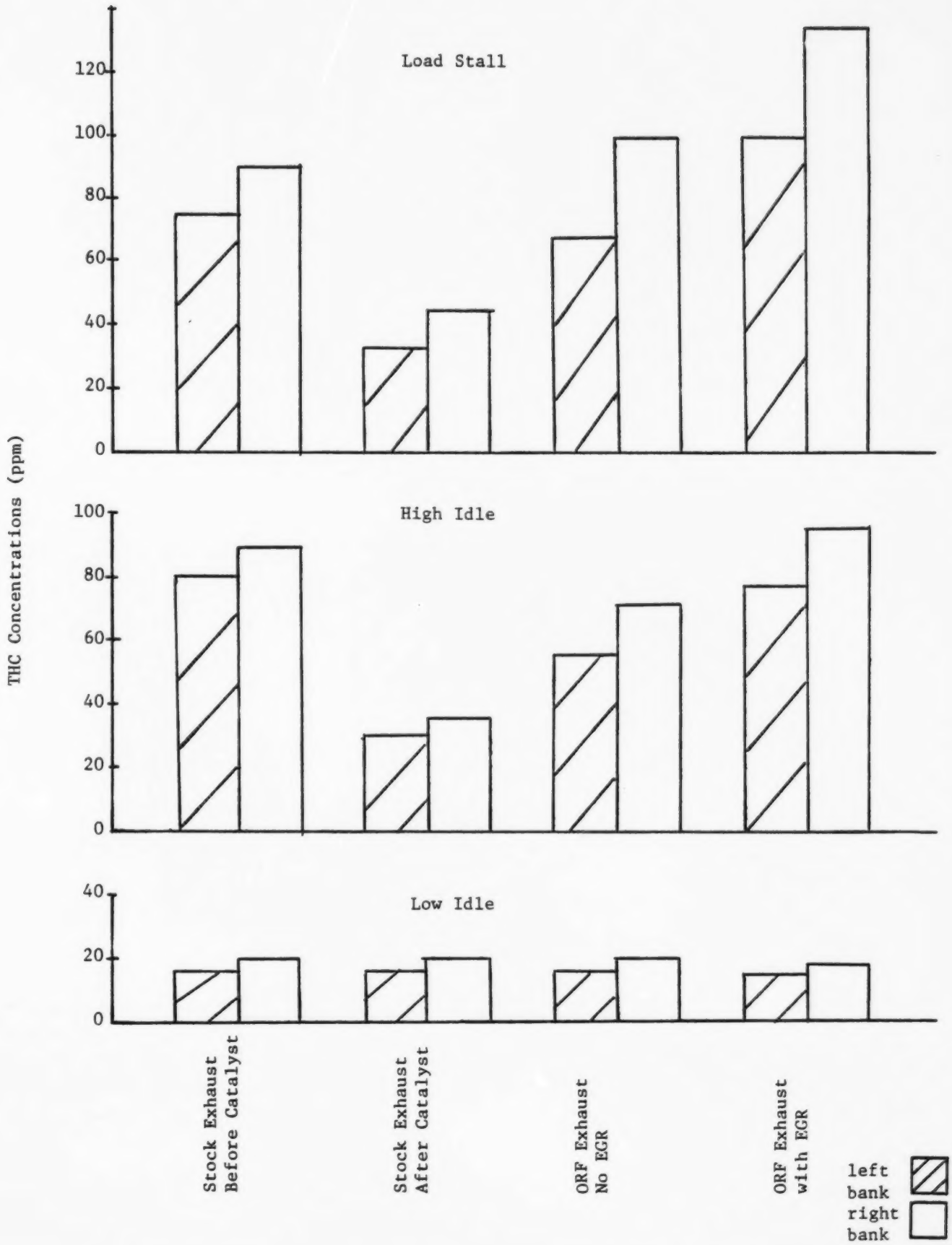


Figure 17: NO Emissions

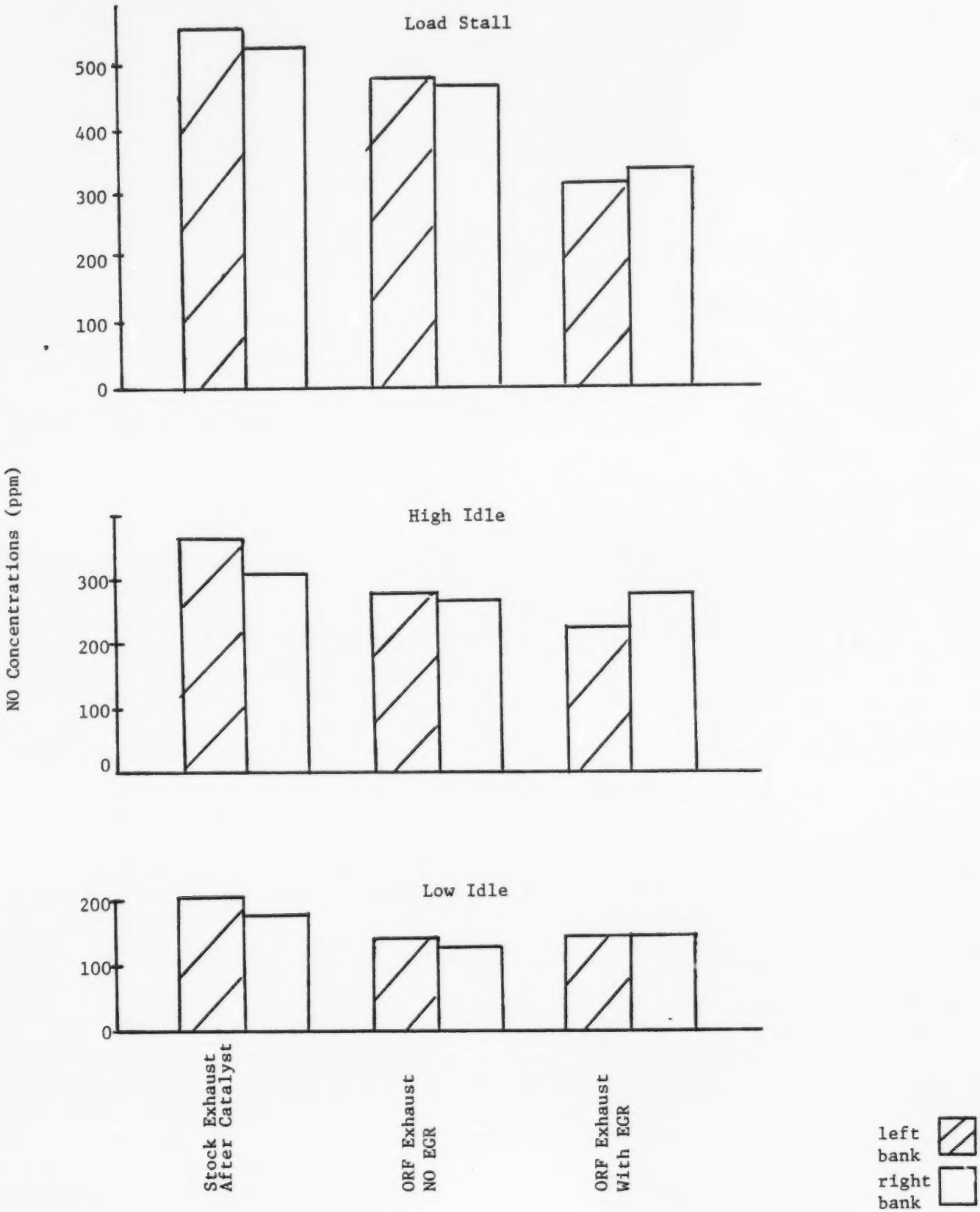


Figure 18: NO_x Emissions

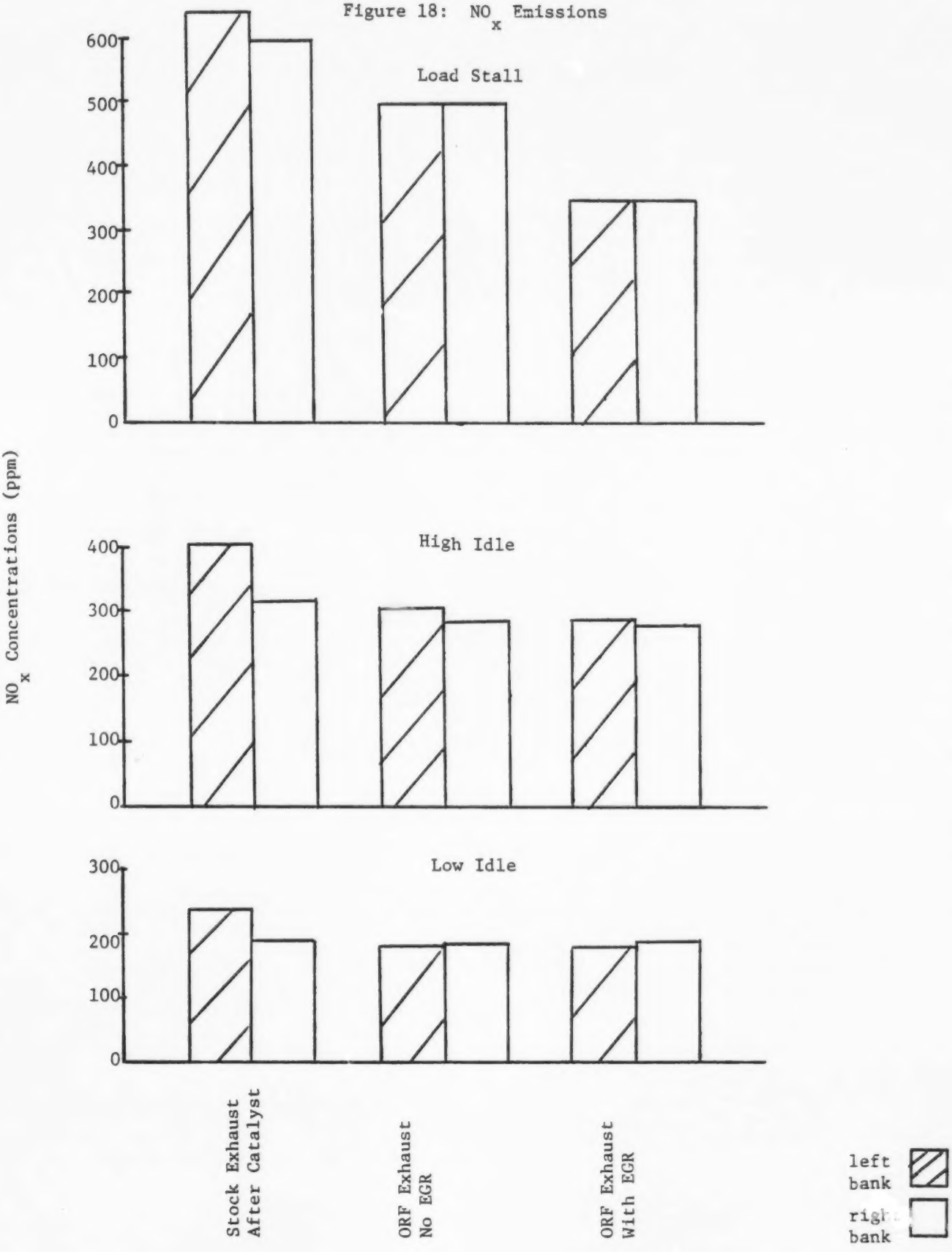
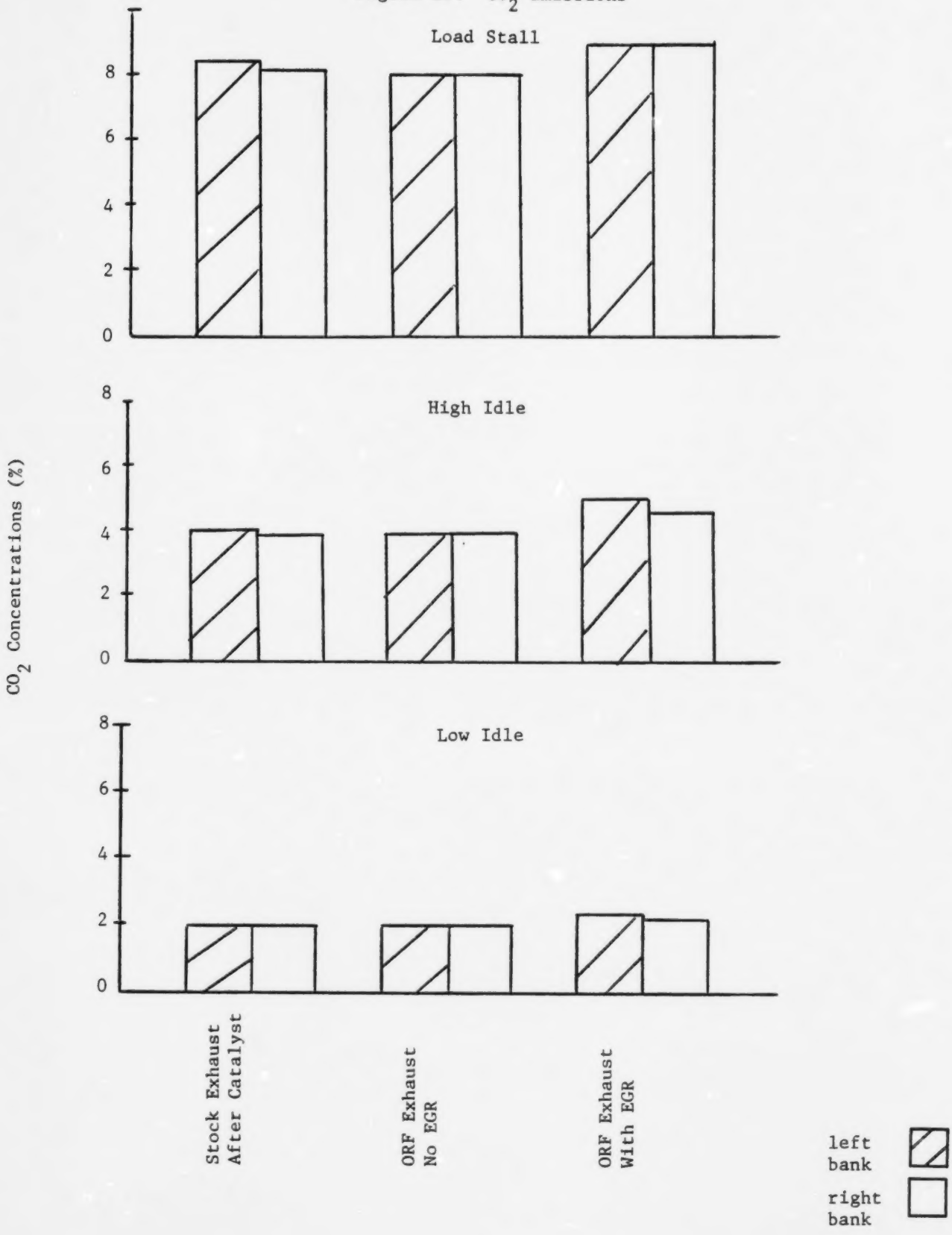


Figure 19: CO_2 Emissions



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